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The Organisms Living Around Energized Submarine Power Cables, Pipe, and Natural Sea Floor in the Inshore Waters of Southern California

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Abstract.—Between 1 February 2012 and 26 February 2014 using scuba, we surveyed the fishes, invertebrates, and macrophytes living on two energized submarine power cables, an adjacent pipe, and nearby natural habitat in southern California at bottom depths of 10–11 m and 13–14 m. Over the course of the study, average electromagnetic field (EMF) levels at the two cables (A and B) were statistically similar (Cable A = 73.0μT, Cable B = 91.4μT) and were much higher at these two cables than at either the pipe (average = 0.5μT) or sand (0μT). Overall, our study demonstrated that 1) the fish and invertebrate communities on cables, pipe, and natural habitat strongly overlapped and 2) there were no differences between the shallower and deeper fish and invertebrate communities. We saw no evidence that fishes or invertebrates are either preferentially attracted to, or repelled by, the EMF emitted by the cables. Any differences in the fish or invertebrate densities between cables, pipe, and natural habitat taxa were most likely due to the differences in the physical characteristics of these habitats. As with the fishes and invertebrates, macrophytes did not appear to be responding to the EMF emitted by the cables. Rather, it is likely that differences in the plant communities were driven by site depth and habitat type.

It is likely that for the foreseeable future, offshore renewable energy technologies will focus on the generation of electricity from renewable resources (e.g., wind and wave). Specifically in U.S. waters, there has been substantial interest in wind energy off the East Coast of the United States (Petruny-Parker et al. 2015; BOEM 2014), both wind and wave energy off the Pacific Coast (Boehlert et al. 2013), and harnessing tidal energy in Puget Sound (Thomson et al. 2012). These technologies harness energy from an array of individual devices and, through power cables, send electricity to shore via cables. These cables will transmit either alternating current or direct current, and, if the cable uses alternating current, this current will generate both electric and magnetic fields around these cables.

Research has shown that cartilaginous and some bony fishes, as well as at least some invertebrates, are sensitive to electromagnetic fields (EMF) and that these fields can alter the behavior of these organisms (Kalmijn 1982; Formicki et al. 2004; Tanski et al. 2005; and summarized in Normandeu et al. 2011). However, worldwide, only a few studies have been conducted to document the effects of EMF on marine organisms *in situ* (DONG Energy and Vattenfall 2006; Ohman et al. 2007; Westerberg and Lagenfelt 2008) or in a semi-artificially enclosed mesocosm (Gill et al. 2012). These studies have yielded either equivocal, or at best subtle, evidence of marine organisms responding to artificially induced EMF in a natural or semi-natural environment.

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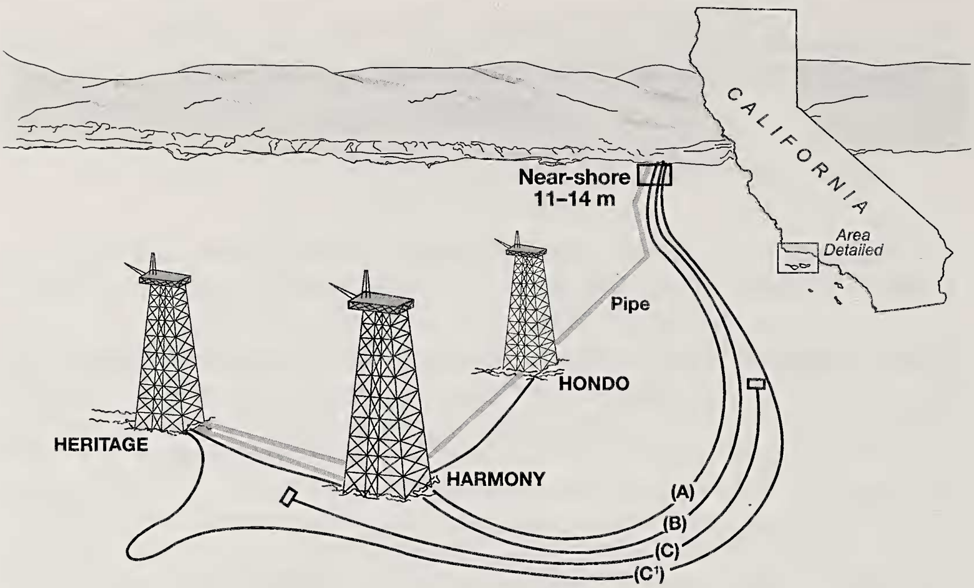

Fig. 1. Location of the energized and unenergized submarine power cables and pipe in the study area.

Submarine transmission cables that power offshore oil platforms in the Pacific Region provide an opportunity to examine potential responses of marine organisms to offshore renewable energy development (Fig. 1). We note that these power cables are industry standard, the type that will be used for connecting devices (35 KV) within renewable energy installations.

Specific objectives of this study were to determine:

1) If differences exist among fish, invertebrate, and plant communities associated with an energized cable habitat and those communities around a nearby pipe and soft seafloor lacking an energized cable.
2) If electro-sensitive species that are regionally important, such as sharks and rays, respond (via either attraction or repulsion) to the EMFs of an *in situ* power transmission cable.
3) The potential effectiveness of the commonly proposed mitigation of cable burial.

Materials and Methods

Our surveys were conducted by scuba off the coast of Las Flores Canyon, southern California (34°27.6'N, 120°02.7'W). In this area there are 1) three 20.32 cm (8") diameter submarine power cables (variously energized and unenergized) providing power to three offshore oil platforms and 2) a 30.48 cm (12") diameter pipe running from the platforms to shore (Fig. 1). The furthest distance between the outermost cable and the pipe is about 40 m.

Prior to beginning the study, we found that sections of cable were both exposed and buried by natural disturbances and that EMF levels were lower on the sandy substrate directly over the buried cable than on the exposed cable. Thus to study the effect of the maximum EMF possible, we determined the survey would be conducted along unburied sections of the cable. Divers observed cables and pipeline for exposed continuous 30-m long sections, a standard transect length that we and other research groups have used for fish surveys in the region. We were able to find sufficient lengths of exposed energized cables (known as cables A and B) where fixed

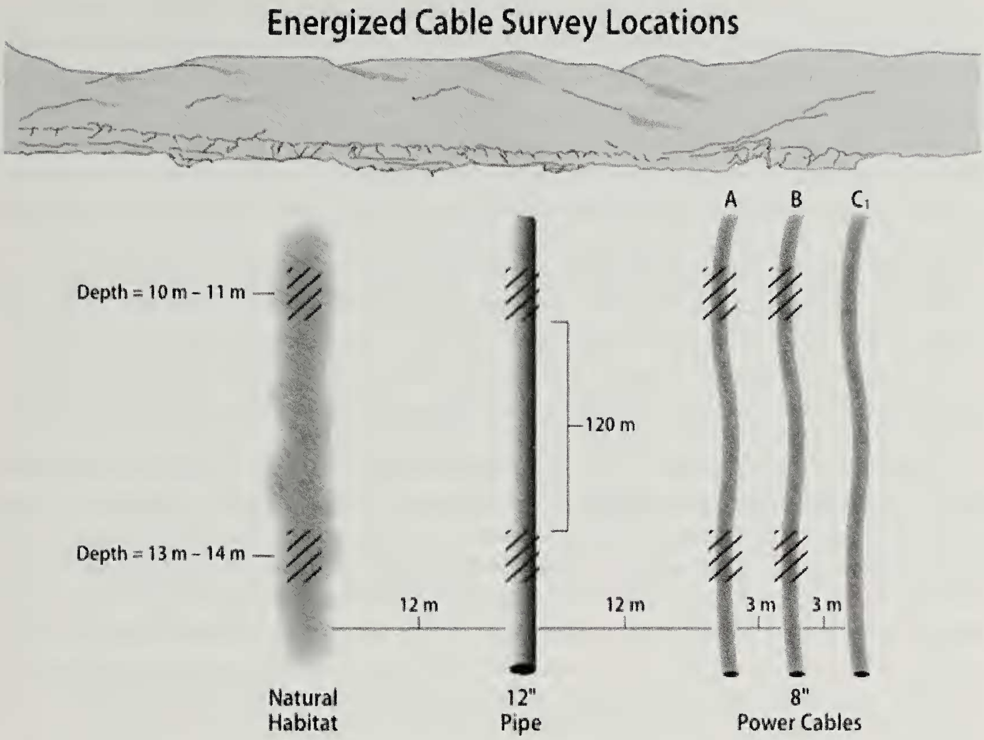

Fig. 2. Schematic illustration of cables, pipe, and natural habitat surveyed by scuba, 1 February 2012–26 February 2014. Cables A and B were energized and were used in this study. The nearshore section of Cable C has been removed. Cable C^1 was unenergized and was not used in this study as it was mostly buried in the sea floor. Distance between cables, pipe, and natural habitat not drawn to scale.

30-m long transects could be set at two bottom depths. An unenergized cable (known as cable C1) was mostly buried, and we did not find any exposed 30-m lengths. Thus, for these surveys, we used the nearby exposed pipe as a surrogate for an unenergized cable. Divers surveyed fishes, invertebrates, and macrophytes along three habitats: an energized submarine power cable, a pipe, and a sandy, natural control area to the west of both cables and pipe (Fig. 2).

The experimental design was comprised of six fixed 30 m-long transects (treatments) of which one was installed in each of three habitats (along a cable, the pipe, and over sandy bottom) and in each of two depths (shallow, 10–11 m; and slightly deeper waters, 13–14 m depth). The end of the shallow transects and beginnings of the deep ones were separated by about 120 m. The beginning and ending of each transect in each habitat was marked by sand anchors as was each 5 m segment along each transect. Transects were 2 m wide, centered on the pipe or cable or an imaginary line between sand anchors that delineated the sandy control transect. Surveys of fishes, macroinvertebrates, and macrophytes were conducted every 2–4 weeks along the six transects during daylight hours by two divers.

At the beginning of the study we measured the EMF emitted by the power cables in our study area and found that two cables, A and B, were energized. We began our cable surveys on energized cable B. However, on 15 May 2013, we detected that cable B had become unenergized and we switched our surveys to energized cable A for the duration of the study. Importantly, both cables A and B had been energized for at least several years before cable B was switched off (D. Gilbert, pers. comm. to M. L.). The magnitude of EMF was measured at the beginning of each survey. A diver recorded readings from a detector placed directly against the cable, pipe, and sand. We used the Kruskal-Wallis one-way ANOVA on ranks to test for a difference in EMF field strength among habitats (Cable B, Cable A, Pipe, and natural habitat). The Wilcoxon test was used for nonparametric comparisons to identify where the EMF differed. The first diver surveyed all fishes encountered within 2 m above the substrate. Fish were identified to species, counted, and sized by eye to the nearest centimeter. A second diver followed and recorded the number of macrophytes in the 2 m swath centered over the cable and pipe or on the sand. The quantification of macrophytes was used to determine if these structure-forming organisms differentially modified the habitats. The second diver also recorded macroinvertebrates (i.e., cnidarians, mollusca, crustaceans, and echinoderms) encountered within the same 2-m-wide sampling area. Only individual invertebrates of at least 10 cm in any dimension were recorded.

We used the Kolmogorov Smirnov Two-Sample test to evaluate whether the size frequency distribution of all fishes differed between the cable, pipe, and natural habitats. Mean lengths among habitats were compared using Welch's test. The fish length observations from both cables A and B were combined for this analysis. We employed the permutational analysis of variance routine in PERMANOVA + for PRIMER (Anderson et al. 2008) to test the response (counts per transect) of the fish, invertebrate, and macrophyte communities, separately, to one or more of the factors: habitat (cable, pipe, natural), depth (shallow, deep), and time (survey). The dataset was divided into two periods; the first when cable B was surveyed and the second when cable A was surveyed. This was a reasonable approach given that the two cable environments were seen to be quite different in terms of the structure-forming macrophyte community that could possibly affect fish and mobile macroinvertebrate abundance. By analyzing data separately from each cable, we were able to determine whether, if a species was more abundant at either a cable or pipe, this pattern occurred at both energized cables (implying that EMF may have been responsible) or only at one of the cables (implying that some other environmental factor was responsible). The experimental design was a balanced, repeated measures 3-way analysis with fixed factors for each period of surveys. During each survey date, we sampled six different treatments (i.e., transects) without replication. The terms of the model were habitat, depth, time, habitat x depth, habitat x time, and depth x time. If the effect of habitat on the abundance of a species was significant ($p<0.05$), then posthoc PERMANOVA permutational t-tests were run for independent pairwise comparisons of abundance between cable, pipe, and natural habitat. P-values in the PERMANOVA routines were calculated using 9999 permutations that generated the test statistic distribution under a true null hypothesis based on the resemblance between the samples. The observations of fish and invertebrate counts per transect were log $(x+1)$ transformed and the macrophyte dataset of counts per transect was square-root transformed before calculating the Bray-Curtis similarity coefficients that quantified the resemblance between multivariate transect samples. We used the PERMDISP routine in PRIMER to determine that either $\log(X+1)$ or square root transformations of the abundance data (count per transect) reduced the heterogeneity of dispersion of multivariate samples among the different experimental treatments. Similarly, we used the permutational analysis of variance routine to test the response (number per transect) of abundant individual species of fishes, invertebrates, and macrophytes to the same factors. The individual species data were transformed using either $\log(x+1)$ or square-root of x. The test statistic for individual species is based on a Euclidean distance matrix between samples (Anderson et al. 2008).

We used multidimensional scaling (MDS) ordination in PRIMER v6 (Clarke and Gorley, 2006) to visualize assemblage groupings of transect samples by habitat and depth. As a complement to the PERMANOVA analysis, we used a two-way crossed analysis of similarity (ANOSIM) in PRIMER to evaluate the degree of overlap in species composition across habitat and depth.

Table 1. All dates of surveys on energized cables, pipe, and natural habitat. Fishes and plants were surveyed on all dates; invertebrates were surveyed from 22 June 2012 to 26 February 2014. Surveys were conducted on energized Cable B from 1 February 2012 to 15 May 2013 and on energized Cable A from 14 June 2013 to 26 February 2014.

2012								
1 Feb.	22 Feb.	8 Mar.	27 Mar	12 Apr.	24 Apr.	9 May	8 June	22 June
13 July	25 July	10 Aug.	22 Aug	11 Sept.	2 Nov.	7 Dec.		
2013								
8 Jan.	5 Feb.	28 Feb.	12 March	3 Apr.	24 Apr.	3 May	15 May	14 June
9 July	16 Aug.	30 Aug.	13 Sept.	30 Sept.	18 Oct.	8 Nov.	20 Nov.	6 Dec.
31 Dec.								
2014								
15 Jan.	12 Feb.	26 Feb.						

ANOSIM operates on the resemblance matrix to test the null hypothesis that there are no assemblage differences between pipe, cable, and natural habitats (factor A), allowing that there may be shallower/deeper differences (factor B), The ANOSIM sample test statistic, R, ranges from 0 (no difference between groups) to 1 (all dissimilarities between the groups are larger than any dissimilarities among samples with either group). A statistically significant ($p<0.05$) but negligibly small R-value close to 0 indicates that species composition differ between habitats, but strongly overlap.

Results

From 1 February 2012 to 26 February 2014, fishes and macrophyte surveys were conducted from the beginning to end of the study. Invertebrate surveys were conducted beginning on 22 June 2012 and continued until the end of the study. Surveys were conducted on a total of 38 days (Table 1). We note that the natural habitat was sand and eelgrass. Over the course of the study, average EMF levels at the two cables (A and B) were statistically similar (Cable A = 73.0μT, Cable B = 91.4μT) and were statistically higher at the two cables compared to the pipe (average = 0.5μT) or sand (0μT) (Fig. 3, Table 2). We note that previous studies have demonstrated that EMF levels reach background levels about one meter from this cable (Love et al. 2015, 2016).

We found that the fish community varied among the cables, pipe, and natural habitat; however, there was significant interaction between the effects of habitat and depth on assemblage structure (Table 3). Furthermore, the 3-dimensional MDS plots of the assemblages from transect samples demonstrates there is substantial overlap of the habitat groupings during the periods when Cable A (global $R=0.043$, $p=0.007$; Fig. 4) and Cable B were surveyed (global $R=0.253$, $p=0.0001$; Fig. 5). Depth-related differences appeared to be somewhat more pronounced when

Table 2. Wilcoxon test values comparing EMF field strengths of two energized cables, pipe, and natural habitat, 2012–2014. NH = natural habitat.

Site	Site	Mean Difference	Standard Error	Z	p-value
Cable B	Cable A	5.95	4.15	1.43	0.15
NH	Cable A	−32.46	4.40	−7.38	<.0001
Pipe	Cable A	−34.46	5.30	−6.50	<.0001
Pipe	Cable B	−36.39	5.30	−6.87	<.0001
NH	Cable B	−36.97	4.67	−7.92	<.0001
NH	Pipe	−43.74	5.34	−8.18	<.0001

Table 3. P-values from the repeated measures PERMANOVA testing the effects of habitat (HA), depth (IN), and sampling date (DA) on fish community structure and density of individual taxa and from PERMANOVA pairwise tests for differences between habitats for the periods when Cables B and A were surveyed. YOY = young-of-the-year. Species selected were those that comprised at least 1% of all fishes observed. Statistically significant results are underlined.

Cable B	HA	IN	DA	HAxIN	HAxDA	INxDA	Cable, pipe	Cable, natural	Pipe, natural
Fish community	0.0001	0.0287	0.0001	0.0127	0.5245	0.1356	0.0016	0.0051	0.0002
Taxon:									
Oxyjulis californica	0.0347	0.9836	0.0001	0.0144	0.8534	0.7389	0.0470	0.0546	0.9695
Citharichthys spp.	0.0007	0.4798	0.0007	0.0325	0.8485	0.0311	0.0001	0.1107	0.0494
Phanerodon furcatus	0.1716	0.1071	0.0313	0.1453	0.7047	0.9496			
Cymatogaster aggregata	0.1005	0.6411	0.0001	0.8181	0.0014	0.9112			
KGB YOY[1]	0.0038	0.0341	0.0006	0.2227	0.1552	0.0718	0.5834	0.0008	0.0092
Brachyistius frenatus	0.3762	0.1600	0.4938	0.4066	0.5033	0.5837			
Sebastes miniatus YOY	0.0916	0.0001	0.0001	0.0121	0.1177	0.0001			
Embiotoca jacksoni	0.0033	0.0916	0.0162	0.8015	0.0412	0.3053	0.0473	0.0661	0.0077
Aulorhynchus flavidus	0.4649	0.3638	0.4685	0.1924	0.4316	0.4712			
Hypsurus caryi	0.4824	0.0381	0.0037	0.1316	0.7651	0.1409			
Damalichthys vacca	0.0573	0.1179	0.4520	0.0224	0.4984	0.4779			
Sebastes caurinus	0.4054	0.3437	0.3529	0.4371	0.5111	0.4941			
Sebastes paucispinis YOY	0.1283	0.4334	0.0667	0.6773	0.9587	0.1426			
Sebastes serranoides/Sebastes flavidus YOY	0.3805	0.2238	0.0121	0.9045	0.8630	0.0053			
Heterostichus rostratus	0.0318	0.2473	0.0162	0.0148	0.6152	0.9351	0.5088	0.0085	0.0092

Table 3. Continued.

Cable A	HA	IN	DA	HAxIN	HAxDA	INxDA	Cable, pipe	Cable, natural	Pipe, natural
Fish community	0.0001	0.0001	0.0001	0.0002	0.0085	0.0001	0.0004	0.0003	0.0001
Taxon:									
Oxyjulis californica	0.0027	0.0161	0.0001	0.0356	0.5450	0.0002	0.0210	0.0949	0.0105
Citharichthys spp.	0.0022	0.0001	0.1479	0.1831	0.5405	0.3673	0.0068	0.8271	0.0025
Phanerodon furcatus	0.0199	0.1778	0.0126	0.2533	0.1704	0.0041	0.0516	0.0108	0.2880
Shiner perch	0.0406	0.5422	0.0291	0.6874	0.0094	0.4952	0.3513	0.0165	0.1574
KGB YOY[1]	0.0001	0.0067	0.0001	0.0466	0.0028	0.1993	0.0001	0.0002	0.0001
Brachyistius frenatus	0.0166	0.0096	0.2912	0.0111	0.5226	0.2729	0.0409	0.0344	0.3601
Sebastes miniatus YOY	0.3610	0.0793	0.0660	0.0805	0.1797	0.0528			
Embiotoca jacksoni	0.0001	0.0001	0.0062	0.0002	0.4926	0.0375	0.1134	0.0003	0.0001
Aulorhynchus flavidus	0.4554	0.7378	0.3142	0.8891	0.9822	0.8205			
Hypsurus caryi	0.0004	0.0006	0.0314	0.0093	0.8955	0.2189	0.0376	0.0429	0.0001
Damalichthys vacca	0.0691	0.0012	0.4786	0.3506	0.4163	0.2530			
Sebastes caurinus	0.0004	0.2144	0.0008	0.3915	0.0298	0.3777	0.1484	0.0003	0.0020
Sebastes paucispinis YOY	0.0438	0.8801	0.8572	0.7147	0.7701	0.5658	0.0480	0.1252	0.3454
Sebastes serranoides/*Sebastes flavidus* YOY	0.4668	0.9484	0.1391	0.3712	0.9601	0.7776			
Heterostichus rostratus	0.0050	0.0306	0.1265	0.0145	0.1581	0.0474	0.0311	0.0070	0.2236

[1] *Sebastes atrovirens, S. caurinus, S. carnatus, S. chrysomelas*

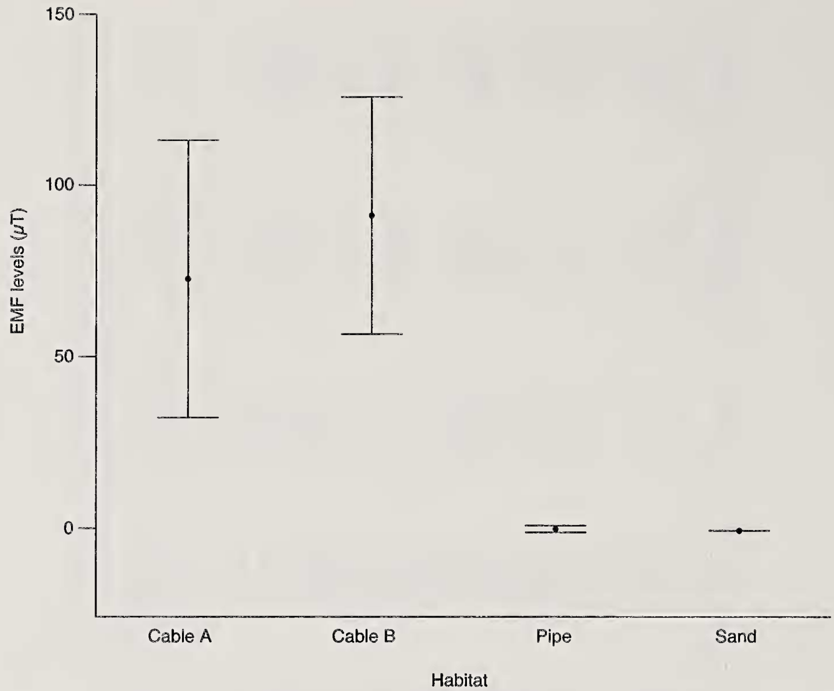

Fig. 3. Electromagnetic field levels measured on cables, pipe, and natural habitat surveyed from 1 February 2012–26 February 2014. Vertical bars represent standard errors.

Cable A is compared to the pipe and natural habitat rather than in similar comparisons with Cable B (Fig. 4 and Fig 5, respectively).

We conducted a total of 38 days of fish surveys during three years. Over all habitats, 4465 individuals representing at least 44 species (summed from Tables 4, 5) were observed. Dominant species included adults of benthic-oriented, schooling taxa (i.e., *Oxyjulis californica, Brachy-*

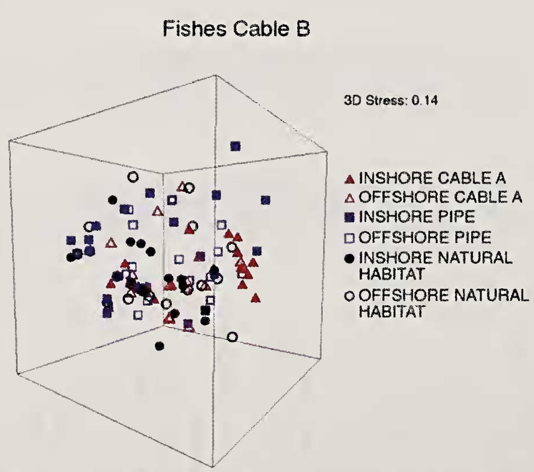

Fig. 4. A 3-d multiple dimensional scaling model comparing the fish assemblages from shallower and deeper transects in Cable B, pipe, and natural habitat.

Table 4. Total count across all habitats and mean (SE) number of fishes per transect in each habitat during period when Cable B was surveyed, 1 February 2012–15 May 2013. Two transects, shallow and deep, were surveyed in each habitat on 23 sampling dates. Number of transect surveys in each habitat, n = 46. YOY = young-of-the-year.

	All habitats	Cable B		Pipe		Natural	
Scientific name	Count	Mean	(SE)	Mean	(SE)	Mean	(SE)
Oxyjulis californica	460	5.35	(1.75)	2.78	(1.63)	1.87	(0.95)
Citharichthys spp.	496	5.48	(1.19)	1.87	(0.48)	3.43	(0.69)
Phanerodon furcatus	111	0.78	(0.48)	0.20	(0.09)	1.43	(0.83)
Cymatogaster aggregata	278	1.13	(0.69)	0.09	(0.06)	4.83	(4.35)
Sebastes atrovirens, S. caurinus, S. carnatus, or *S. chrysomelas* YOY	180	1.72	(0.58)	2.11	(0.83)	0.09	(0.04)
Brachyistius frenatus	75	0.39	(0.15)	1.22	(1.02)	0.02	(0.02)
Sebastes miniatus YOY	228	1.13	(0.57)	3.30	(1.85)	0.52	(0.30)
Sebastes jordani YOY	190	0.43	(0.43)	1.09	(1.09)	2.61	(2.61)
Embiotoca jacksoni	78	0.39	(0.13)	1.20	(0.46)	0.11	(0.09)
Aulorhynchus flavidus	158	0.72	(0.67)	0.41	(0.18)	2.30	(1.82)
Hypsurus caryi	26	0.15	(0.07)	0.28	(0.12)	0.13	(0.07)
Damalichthys vacca	119	0.02	(0.02)	2.54	(1.94)	0.02	(0.02)
Sebastes caurinus	52	0.74	(0.41)	0.33	(0.14)	0.07	(0.04)
Sebastes paucispinis	81	0.28	(0.20)	1.46	(0.88)	0.02	(0.02)
Sebastes serranoides or *S. flavidus* YOY	40	0.13	(0.08)	0.67	(0.57)	0.07	(0.04)
Heterostichus rostratus	23	0.30	(0.15)	0.20	(0.11)	0.00	(0.00)
Sebastes semicinctus	29	0.22	(0.18)	0.41	(0.39)	0.00	(0.00)
Synodus lucioceps	1	0.00	(0.00)	0.00	(0.00)	0.02	(0.02)
Oxylebius pictus	12	0.09	(0.04)	0.17	(0.06)	0.00	(0.00)
Sebastes mystinus	1	0.00	(0.00)	0.02	(0.02)	0.00	(0.00)
Sebastes auriculatus	17	0.00	(0.00)	0.37	(0.35)	0.00	(0.00)
Scorpaenichthys marmoratus	7	0.07	(0.04)	0.09	(0.04)	0.00	(0.00)
Hexagrammos decagrammus	2	0.00	(0.00)	0.04	(0.03)	0.00	(0.00)
Pleuronichthys coenosus	6	0.04	(0.03)	0.02	(0.02)	0.07	(0.05)
Gibbonsia spp.	2	0.02	(0.02)	0.02	(0.02)	0.00	(0.00)
Sebastes dalli	5	0.04	(0.03)	0.07	(0.07)	0.00	(0.00)
Paralabrax clathratus	1	0.02	(0.02)	0.00	(0.00)	0.00	(0.00)
Unidentified Cottidae	3	0.00	(0.00)	0.07	(0.04)	0.00	(0.00)
Leiocottus hirundo	4	0.00	(0.00)	0.07	(0.05)	0.02	(0.02)
Neoclinus blanchardi	1	0.02	(0.02)	0.00	(0.00)	0.00	(0.00)
Ophiodon elongatus	5	0.04	(0.03)	0.00	(0.00)	0.07	(0.05)
Paralichthys californicus	1	0.00	(0.00)	0.00	(0.00)	0.02	(0.02)
Sebastes atrovirens	3	0.02	(0.02)	0.04	(0.03)	0.00	(0.00)
Unidentified fishes	3	0.07	(0.05)	0.00	(0.00)	0.00	(0.00)
Gibbonsia spp.	2	0.00	(0.00)	0.04	(0.03)	0.00	(0.00)
Sebastes carnatus	1	0.02	(0.02)	0.00	(0.00)	0.00	(0.00)
Paralabrax nebulifer	1	0.02	(0.02)	0.00	(0.00)	0.00	(0.00)
Pleuronichthys decurrens	1	0.00	(0.00)	0.00	(0.00)	0.02	(0.02)
Porichthys spp.	1	0.00	(0.00)	0.02	(0.02)	0.00	(0.00)
Rathbunella spp.	1	0.00	(0.00)	0.02	(0.02)	0.00	(0.00)
Sebastes rastrelliger	1	0.00	(0.00)	0.02	(0.02)	0.00	(0.00)
Urobatis halleri	1	0.02	(0.02)	0.00	(0.00)	0.00	(0.00)
All fishes	2707	19.93	(3.91)	22.24	(5.56)	17.76	(5.85)

Table 5. Total count across all habitats and mean (SE) number of fishes per transect in each habitat during period when Cable A was surveyed, 14 June 2013–26 February 2014. Two transects, shallow and deep, were surveyed in each habitat on 14 sampling dates. Number of transect surveys in each habitat, n = 28. YOY = young-of-the-year.

	All habitats	Cable A		Pipe		Natural	
Scientific name	Count	Mean	(SE)	Mean	(SE)	Mean	(SE)
Oxyjulis californica	414	3.96	(1.14)	8.46	(2.13)	2.36	(0.56)
Citharichthys spp.	140	2.14	(0.50)	0.71	(0.20)	2.14	(0.48)
Phanerodon furcatus	241	4.29	(1.29)	2.75	(1.19)	1.57	(0.65)
Cymatogaster aggregata	56	0.00	(0.00)	0.29	(0.29)	1.71	(1.43)
Sebastes atrovirens, S. caurinus, S. carnatus, or *S. chrysomelas* YOY	151	1.79	(0.54)	3.50	(0.81)	0.11	(0.06)
Brachyistius frenatus	199	6.18	(2.76)	0.79	(0.64)	0.14	(0.11)
Sebastes miniatus YOY	27	0.36	(0.15)	0.43	(0.17)	0.18	(0.15)
Sebastes jordani YOY	0	0.00	(0.00)	0.00	(0.00)	0.00	(0.00)
Embiotoca jacksoni	104	1.68	(0.70)	2.00	(0.48)	0.04	(0.04)
Aulorhynchus flavidus	7	0.07	(0.05)	0.04	(0.04)	0.14	(0.07)
Hypsurus caryi	123	1.29	(0.30)	2.61	(0.60)	0.50	(0.23)
Damalichthys vacca	23	0.29	(0.15)	0.46	(0.17)	0.07	(0.05)
Sebastes caurinus	54	0.71	(0.27)	1.21	(0.42)	0.00	(0.00)
Sebastes paucispinis	18	0.54	(0.24)	0.00	(0.00)	0.11	(0.11)
Sebastes serranoides or *Sebastes flavidus* YOY	32	0.43	(0.14)	0.43	(0.26)	0.29	(0.25)
Heterostichus rostratus	22	0.54	(0.18)	0.18	(0.07)	0.07	(0.05)
Sebastes semicinctus	15	0.21	(0.15)	0.32	(0.25)	0.00	(0.00)
Synodus lucioceps	26	0.79	(0.68)	0.00	(0.00)	0.14	(0.14)
Oxylebius pictus	13	0.29	(0.13)	0.18	(0.09)	0.00	(0.00)
Sebastes mystinus	19	0.36	(0.19)	0.32	(0.22)	0.00	(0.00)
Sebastes auriculatus	2	0.04	(0.04)	0.04	(0.04)	0.00	(0.00)
Scorpaenichthys marmoratus	7	0.00	(0.00)	0.21	(0.08)	0.04	(0.04)
Hexagrammos decagrammus	10	0.07	(0.05)	0.29	(0.16)	0.00	(0.00)
Pleuronichthys coenosus	6	0.14	(0.08)	0.04	(0.04)	0.04	(0.04)
Gibbonsia spp.	8	0.04	(0.04)	0.25	(0.08)	0.00	(0.00)
Sebastes dalli	5	0.14	(0.14)	0.04	(0.04)	0.00	(0.00)
Paralabrax clathratus	6	0.14	(0.14)	0.07	(0.05)	0.00	(0.00)
Coryphopterus nicholsii	6	0.00	(0.00)	0.21	(0.12)	0.00	(0.00)
Unidentified Cottidae	3	0.00	(0.00)	0.11	(0.08)	0.00	(0.00)
Leiocottus hirundo	2	0.04	(0.04)	0.04	(0.04)	0.00	(0.00)
Neoclinus blanchardi	4	0.07	(0.05)	0.07	(0.05)	0.00	(0.00)
Paralichthys californicus	4	0.00	(0.00)	0.07	(0.05)	0.07	(0.07)
Sebastes atrovirens	1	0.04	(0.04)	0.00	(0.00)	0.00	(0.00)
Syngnathus spp.	3	0.04	(0.04)	0.04	(0.04)	0.04	(0.04)
Sebastes carnatus	1	0.00	(0.00)	0.04	(0.04)	0.00	(0.00)
Cephaloscyllium ventriosum	1	0.00	(0.00)	0.04	(0.04)	0.00	(0.00)
Halichoeres semicinctus	1	0.04	(0.04)	0.00	(0.00)	0.00	(0.00)
Heterodontus francisci	1	0.00	(0.00)	0.04	(0.04)	0.00	(0.00)
Myliobatis californica	1	0.00	(0.00)	0.00	(0.00)	0.04	(0.04)
Phanerodon atripes	1	0.00	(0.00)	0.00	(0.00)	0.04	(0.04)
Unidentified Embiotocidae	1	0.00	(0.00)	0.00	(0.00)	0.04	(0.04)
All fishes	1758	26.86	(4.05)	26.68	(3.47)	9.89	(2.15)

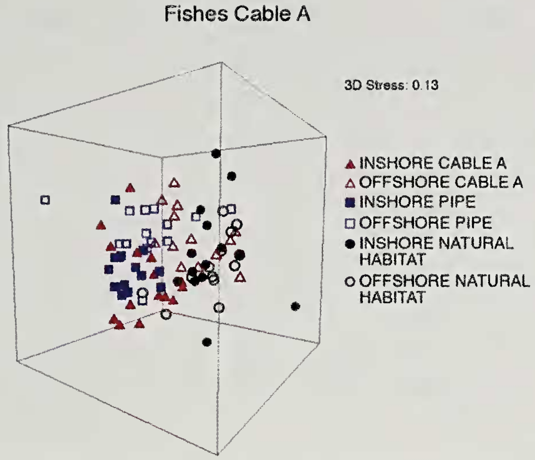

Fig. 5. A 3-d multiple dimensional scaling model comparing the fish assemblages from shallower and deeper transects in Cable A, pipe, and natural habitat.

istius frenatus, *Phanerodon furcatus*, and *Cymatogaster aggregata*), young-of-the-year (YOY) *Sebastes* that had newly settled out of the plankton (particularly *Sebastes chrysomelas*, *S. carnatus*, and *S. atrovirens*), and relatively solitary substrate-oriented species (i.e., *Citharichthys* spp.). *Oxyjulis californica*, *Citharichthys* spp., *Phanerodon furcatus*, YOY *Sebastes*, and *B. frenatus* were the most abundant taxa. *Cables*: At least 35 species and 1,661 individuals were observed over the energized cables. *Oxyjulis californica*, *Citharichthys* spp., *B. frenata*, *P. furcatus*, and YOY *Sebastes* were most abundant (Tables 4, 5). *Pipe*: The number of taxa (37) and individuals (1,712) were similar to those observed on the cables. *Oxyjulis californica*, YOY *Sebastes*, *Sebastes miniatus* YOY, *Damalichthys vacca*, *Embiotoca jacksoni*, and *Citharichthys* spp. were the most abundant taxa on the pipe (Tables 4, 5). *Natural Habitat*: Fewest species (25) and individuals (1,092) were observed over the natural habitat. *Cymatogaster aggregata*, *Citharichthys* spp., *O. californica*, YOY *Sebastes jordani*, *P. furcatus*, and *Aulorhynchus flavidus* were the most commonly observed species (Tables 4, 5).

Fish communities among all habitats were composed primarily of small-sized fishes with most being less than 20 cm long. The mean lengths of fishes (cables = 11.8 cm, pipe = 11.4 cm, natural habitat = 9.7 cm) varied significantly among the three habitats (Welch's Test, $F = 43.7$, $df = 2$, $p < 0.0001$) as did the size distributions (Kolmogorov Smirnov Two-Sample Test: cables versus pipe, $N = 3{,}484$ KS 0.053, $p = <0.0001$; cables versus natural habitat, $N = 2{,}832$ KS 0.147, $p = <0.0001$; pipe versus natural habitat, $N = 2{,}890$ KS 0.117, $p = <0.0001$).

While the overall fish communities were similar among the three habitats, there were some fish species that were statistically more abundant over parts of either the cables or pipe (Table 3, Fig. 6). As examples, *O. californica*, *Citharichthys* spp., and *E. jacksoni* were all more abundant over Cable B than over the pipe (Table 3, Fig. 6). Similarly, *B. frenatus*, *Sebastes paucispinis* YOY, and *Heterostichus rostratus* were more abundant over Cable A compared to the pipe. However, with the exception of *Citharichthys* spp., none of these species were *consistently* more abundant at either the cables or the pipe or over both depths. Rather, in virtually all of these instances these differences were either 1) limited to one of the two cables or 2) were not consistent between depths (Fig. 6). As an example, while *O. californica* was statistically more abundant at Cable B than at the pipe, it was less abundant at Cable A compared to the pipe. Similarly, *Hypsurus*

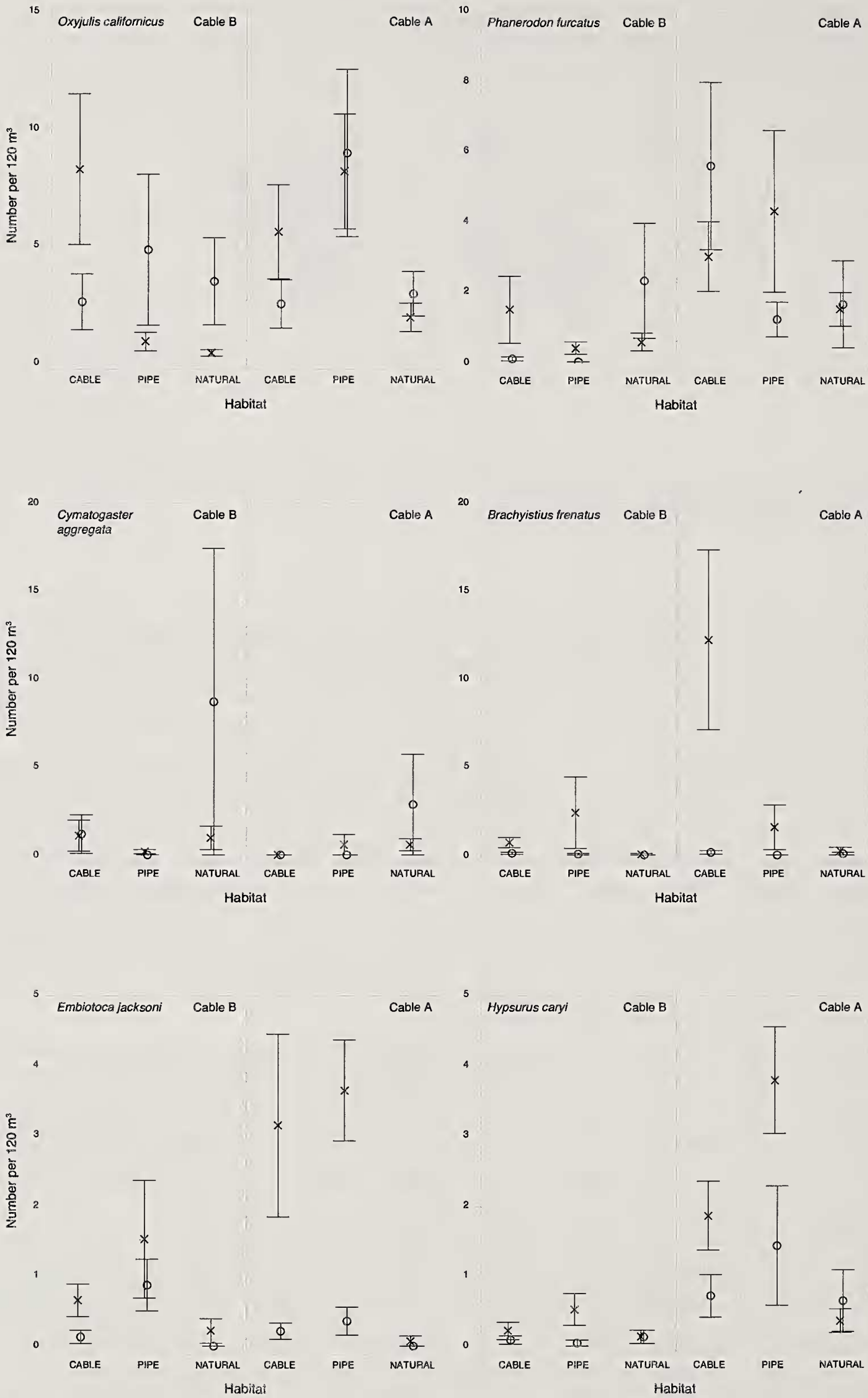

Fig. 6. Mean fish species densities found at the shallower and deeper sites at the three habitats. Data is divided into two periods when 1) Cable B was surveyed and 2) when Cable A was surveyed. KGB = young-of-the-year *Sebastes atrovirens*, *S. carnatus*, *S. chrysomelas*, and *S. caurinus*.

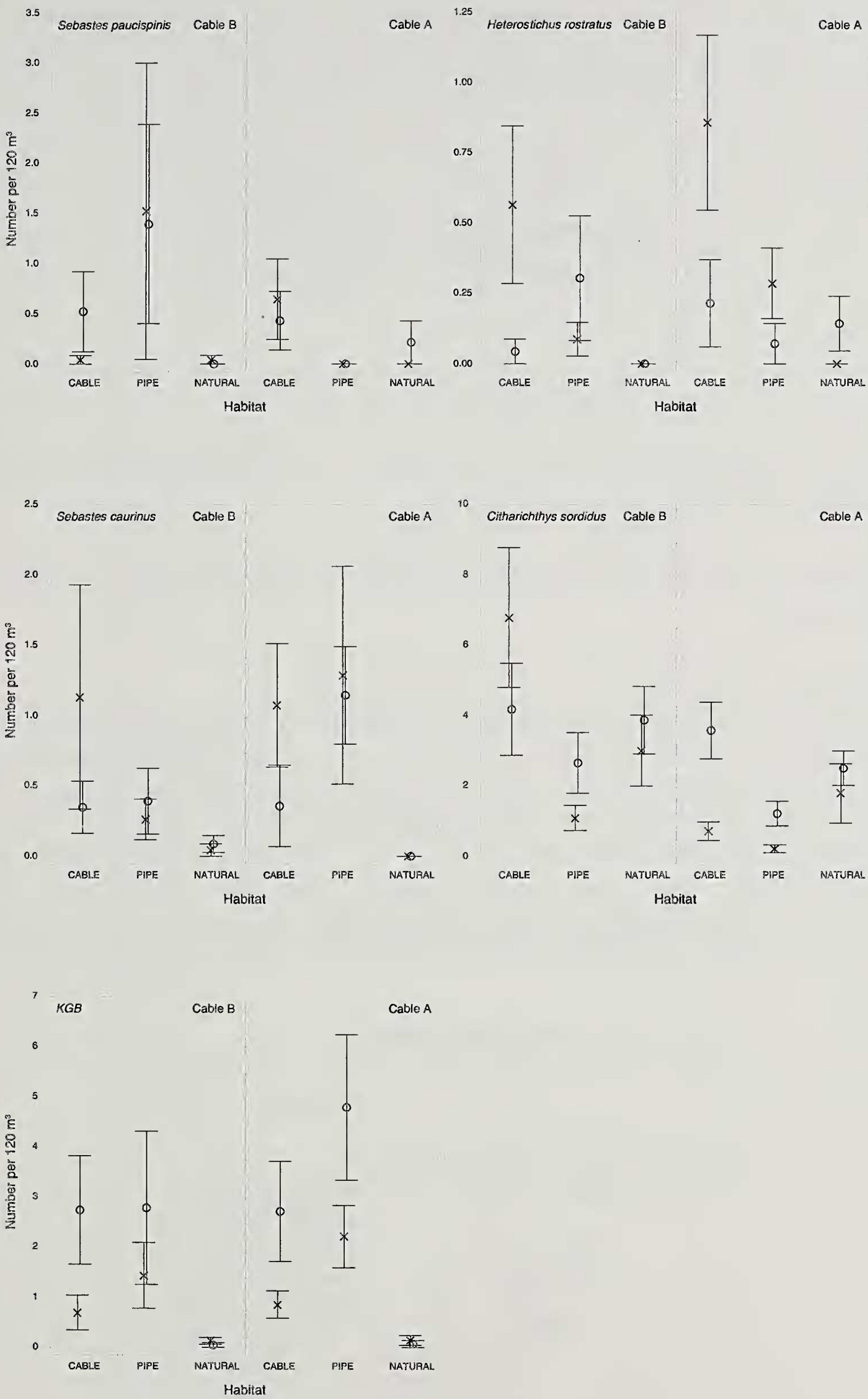

Fig. 6. Continued.

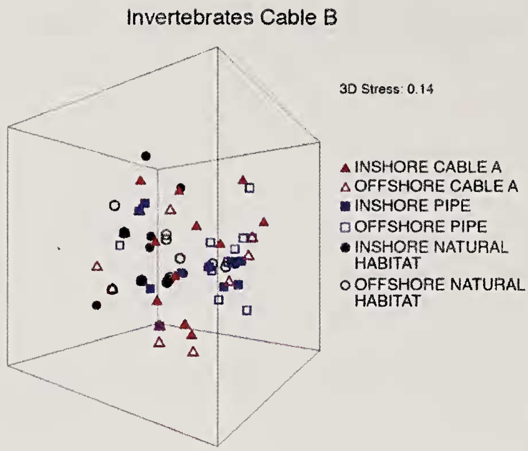

Fig. 7. A 3-d multiple dimensional scaling model comparing the invertebrate assemblages from shallower and deeper transects in Cable B, pipe, and natural habitat.

caryi were more abundant on the inshore parts of the pipe compared to Cable A, but not on the offshore parts.

Invertebrates

As with the fish community, the invertebrate assemblages varied among the cables, pipe, and natural habitat with significant interaction between the effects of habitat and depth on assemblage structure (Table 6). The three-dimensional MDS plots of the assemblages from shallow and deep transect samples demonstrates substantial overlap of the habitat groupings during the periods when both cable B (global R=0.085, p=0.002; Fig. 7) and cable A were surveyed (global R=0.227, p=0.0001; Fig. 8). We conducted a total of 30 days of invertebrate surveys during three years. A total of 802 individuals were observed, comprising at least 19 species (Tables 7, 8). *Patiria miniata*, several species of *Pisaster* sea stars, *Aplysia californica*, *Astropecten*

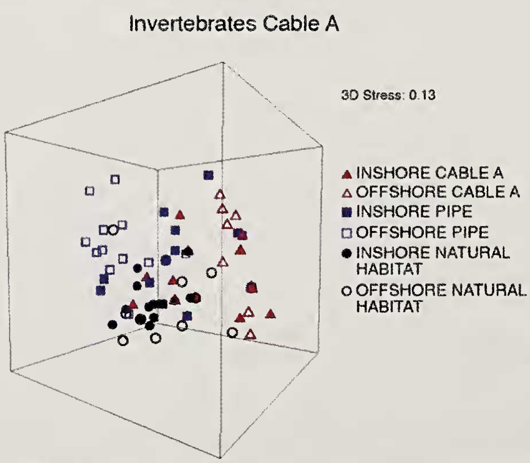

Fig. 8. A 3-d multiple dimensional scaling model comparing the invertebrate assemblages from shallower and deeper transects in Cable A, pipe, and natural habitat.

Table 6. P-values from the repeated measures PERMANOVA testing the effects of habitat (HA), depth (IN), and sampling date (DA) on invertebrate community structure and density of individual taxa and from PERMANOVA pairwise tests for differences between habitats for the periods when Cables B and A were surveyed. Species selected were those that comprised at least 1% of all invertebrates observed. Statistically significant effects and differences are underlined.

Cable B	HA	IN	DA	HAxIN	HAxDA	INxDA	Cable, pipe	Cable, natural	Pipe, natural
Invertebrate community	0.0017	0.2021	0.0238	0.0365	0.4545	0.1237	0.0354	0.0610	0.0061
Taxon:									
Pisaster spp.	0.0011	0.2884	0.0123	0.2881	0.0532	0.3558	0.0196	0.1248	0.0038
Patiria miniata	0.1528	0.9272	0.6332	0.0046	0.2595	0.1744			
Aplysia californica	0.0327	0.4780	0.1149	0.5209	0.2109	0.0716	0.6433	0.0455	0.0020
Kelletia kelletii	0.1097	0.1175	0.1485	0.6568	0.6353	0.0738			
Parastichopus spp.	0.3903	0.3395	0.3746	0.4344	0.5065	0.4964			
Metacarcinus spp./*Cancer* spp.	0.0303	0.4645	0.7884	0.0338	0.8292	0.3765	0.0650	0.0423	0.8462
Cable A	HA	IN	DA	HAxIN	HAxDA	INxDA	Cable, pipe	Cable, natural	Pipe, natural
Invertebrate community	0.0001	0.0054	0.0001	0.0044	0.2620	0.2436	0.0005	0.0001	0.0002
Taxon:									
Pisaster spp.	0.0001	0.0031	0.0015	0.0091	0.5799	0.1771	0.0009	0.1841	0.0003
Patiria miniata	0.0001	0.1323	0.0071	0.0008	0.1950	0.0064	0.0003	0.0002	0.3001
Astropecten armatus	0.0190	0.0205	0.0042	0.0573	0.1447	0.4878	0.3525	0.0098	0.0855
Aplysia californica	0.0007	0.2111	0.0141	0.7424	0.0036	0.8056	0.0174	0.0969	0.0009
Kelletia kelletii	0.2817	0.6565	0.2405	0.7408	0.7233	0.0881			
Parastichopus spp.	0.0001	0.0017	0.0246	0.0060	0.0233	0.5548	0.0004	not defined	0.0002
Metacarcinus spp./*Cancer* spp.	0.8382	0.3927	0.4557	0.8323	0.9260	0.9788			

Table 7. Total counts across all habitats and mean (SE) number of invertebrates in each habitat during period when Cable B was surveyed. Two transects, shallow and deep, were surveyed in each habitat on 22 June–15 May 2013 sampling dates. Number of transect surveys in each habitat, n=30.

Scientific name	Total count	CABLE B Mean	CABLE B SE	Pipe Mean	Pipe SE	Natural Mean	Natural SE
Patiria miniata	78	0.43	0.14	0.97	0.29	1.20	0.32
Pisaster spp.	70	0.73	0.31	1.27	0.25	0.33	0.14
Aplysia californica	19	0.33	0.12	0.27	0.11	0.03	0.03
Kelletia kelletii	27	0.37	0.19	0.03	0.03	0.50	0.22
Parastichopus sp.	1	0.00	0.00	0.03	0.03	0.00	0.00
Metacarcinus sp. *and Cancer* sp.	18	0.47	0.18	0.07	0.05	0.07	0.07
Loligo opalescens eggs	20	0.00	0.00	0.67	0.67	0.00	0.00
Pugettia spp.	18	0.30	0.13	0.27	0.14	0.03	0.03
Loxorhynchus spp.	12	0.10	0.06	0.13	0.06	0.17	0.08
Dendraster excentricus	19	0.10	0.07	0.03	0.03	0.50	0.28
Octopus spp.	2	0.03	0.03	0.00	0.00	0.03	0.03
Metacarcinus gracilis	5	0.07	0.07	0.07	0.07	0.03	0.03
Dermasterias imbricata	3	0.10	0.10	0.00	0.00	0.00	0.00
Megathura crenulata	1	0.00	0.00	0.03	0.03	0.00	0.00
Pycnopodia helianthoides	1	0.03	0.03	0.00	0.00	0.00	0.00

Table 8. Total counts across all habitats and mean (SE) number of invertebrates in each habitat during period when Cable A was surveyed. Two transects, shallow and deep, were surveyed in each habitat on 14 June 2013–26 February 2014 sampling dates. Number of transect surveys in each habitat, n=28.

Scientific name	Total count	CABLE A Mean	CABLE A SE	Pipe Mean	Pipe SE	Natural Mean	Natural SE
Patiria miniata	155	0.75	0.26	2.14	0.38	2.64	0.41
Pisaster spp.	92	0.46	0.17	2.61	0.66	0.21	0.08
Strongylocentrotus purpuratus	100	0.00	0.00	3.57	3.57	0.00	0.00
Aplysia californica	44	0.29	0.12	1.25	0.44	0.04	0.04
Astropecten armatus	51	0.29	0.10	0.43	0.12	1.11	0.37
Kelletia kelletii	21	0.04	0.04	0.46	0.33	0.25	0.15
Parastichopus sp.	21	0.04	0.04	0.68	0.18	0.04	0.04
Metacarcinus sp. *and Cancer* sp.	4	0.07	0.05	0.04	0.04	0.04	0.04
Pugettia spp.	1	0.00	0.00	0.00	0.00	0.04	0.04
Loxorhynchus spp.	7	0.04	0.04	0.11	0.06	0.11	0.08
Octopus spp.	10	0.07	0.07	0.29	0.10	0.00	0.00
Dermasterias imbricata	1	0.00	0.00	0.00	0.00	0.04	0.04
Panulirus interruptus	1	0.04	0.04	0.00	0.00	0.00	0.00

armatus, and *Kelletia kelletii* were observed most often. By group, sea stars were the most abundant, comprising 56.8% of all invertebrates observed. *Cables*: We recorded 157 individuals of at least 15 species at the cable sites. *P. miniata*, *Pisaster* sea stars, and *A. californica* were most abundant (Tables 7, 8). *Pipe*: A total of 422 individual invertebrates, more than any other site, were observed at the pipe. However, 100 of these individuals were comprised of a one-time recorded aggregation of *Strongylocentrotus purpuratus*. Like the cables, we recorded 15 species along the pipe (Tables 7, 8). *Natural Habitat*: *Patiria miniata* and *K. kelletii* predominated in the natural habitat, where we recorded 223 individuals, of 13 species (Tables 7, 8). Again, consistent with what we observed for fish species, in comparing cables with the pipe, only one invertebrate species was consistently more abundant in either habitat: *Pisaster* spp. were more abundant over the pipe (Table 8, Fig. 9). Several other species, such as *P. miniata*, *Parastichopus* spp., *A. californica*, and *Parastichopus* spp. were not consistently more abundant on either cables or pipe.

Macrophytes

In contrast to the fish and invertebrate communities, the macrophyte assemblages were strikingly distinct from one another by habitat and depth. The interaction between these two effects on assemblage structure was significant (Table 9). The 3-dimensional MDS plots of the assemblages from shallow and deep transect samples demonstrates no overlap of the habitat groupings during the periods when Cable B (global $R=0.998$ $p=0.0001$; Fig. 10) and Cable A were surveyed (global $R=0.993$, $p=0.0001$; Fig. 11).

We conducted a total of 38 days of surveys during three years. A total of 76358 individual macrophytes (many likely observed repeatedly on sequential survey days) were tallied, comprising at least five species (Table 10). Overall, *Zostera marina* was most abundant (and found only on the natural habitat), followed by *Pterygophora californica*, *Cystoseira* spp., *Macrocystis pyrifera*, and *Laminaria* spp. *Cables*: Overall, *Pterygophora californica* dominated the cable community, although *Cystoseira* spp. and *Laminaria* spp. were not uncommon (Table 10). However, note that *P. californica* was very abundant on Cable B (particularly shallower), but much less so on Cable A (Table 10). *Zostera marina* grew on the sand near the cable. *Macrocystis pyrifera* grew very sparsely on the shallower Cable B habitat, was more common on the shallower part of Cable A, and was essentially absent from the deeper cables (Fig. 12). *Pipe*: *Cystoseira* spp. was the most common macrophyte on the pipe (Table 10). *Cystoseira* spp. was about twice as abundant shallower than deeper while *Laminaria* spp. was almost absent from the shallower site and nearly as abundant as *Cystoseira* spp. deeper (Fig. 12). Relatively few *P. californica* were observed on the pipe and both *M. pyrifera* and *Z. marina* were almost absent. *Natural Habitat*: *Zostera marina* was the only macrophyte growing on the sandy sea floor of the natural habitat (Table 10). It was dense at both the shallower and deeper sites (Fig. 12). As noted above, the macrophyte communities in the three habitats differed among each other and along the inshore and offshore transects. This was reflected in the distribution of all macrophyte species when comparing cable and pipe habitats (Table 10). Unlike with virtually all of the fish species and all of the invertebrate species, the differences in abundances were consistent between both cables and the pipe and at both depths (Fig. 12).

Discussion and Conclusions

We began this study with the understanding that if a species is attracted to an EMF we would expect to find that species in disproportionately larger numbers or densities around the energized cables compared to the pipe or natural habitat. Similarly, if a taxa is repelled by that EMF we

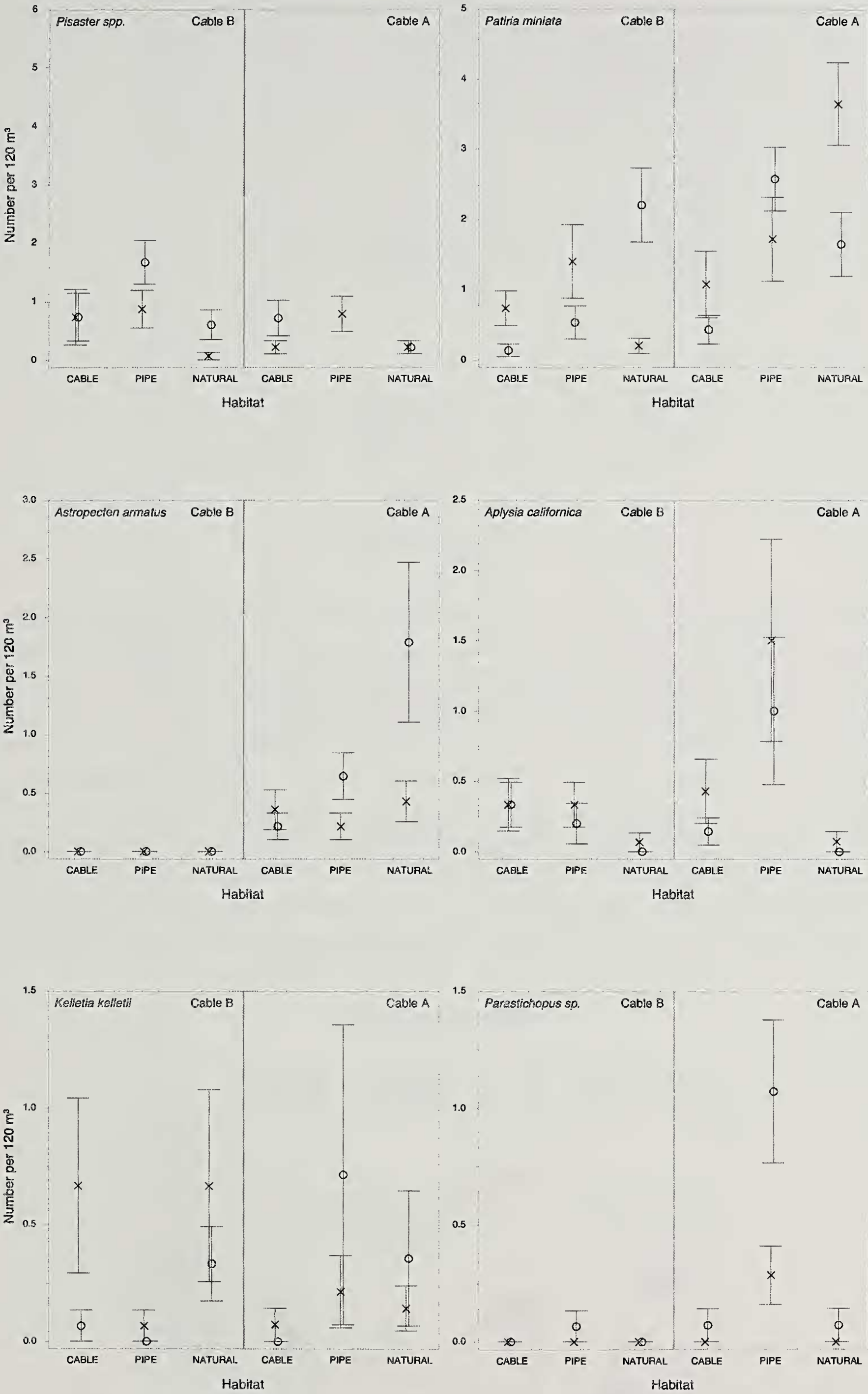

Fig. 9. Mean invertebrate species densities found at the shallower and deeper sites at the three habitats. Data is divided into two periods when 1) Cable B was surveyed and 2) when Cable A was surveyed.

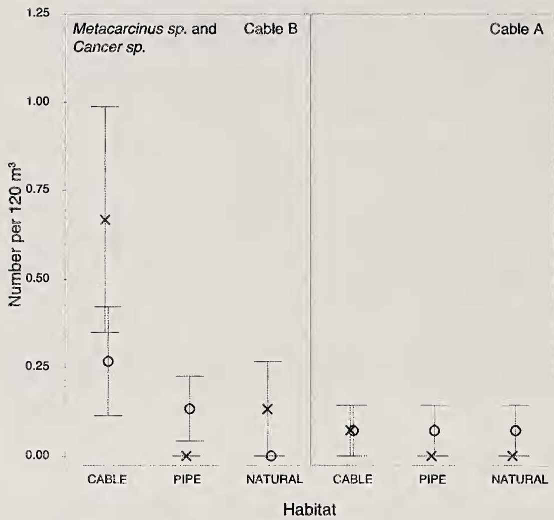

Fig. 9. (Continued).

would expect that species to be present less often or in lower densities at the cables. However, the presence or absence of an EMF is not the only habitat parameter influencing how an organism chooses its habitat. We acknowledge that in this study the cables and pipe differed not only in the production of an EMF but to some extent in the morphology of these habitats. In particular, the pipe was a slightly more complex structure. First, the pipe's diameter (30.48 cm) was somewhat greater than that of the two cables (20.32 cm), and while the cable was sometimes partially buried, the pipe was not. Thus for both reasons the pipe tended to present a somewhat higher profile. In addition, perhaps the greatest structural difference between the cables and pipe was the very high density, particularly on the shallower pipe, of *Cystoceira* sp., a brown alga that was essentially absent from the shallower cable. This alga forms a dense cover near the bottom and small fishes, particularly YOY *Sebastes*, will preferentially inhabit this complex substratum.

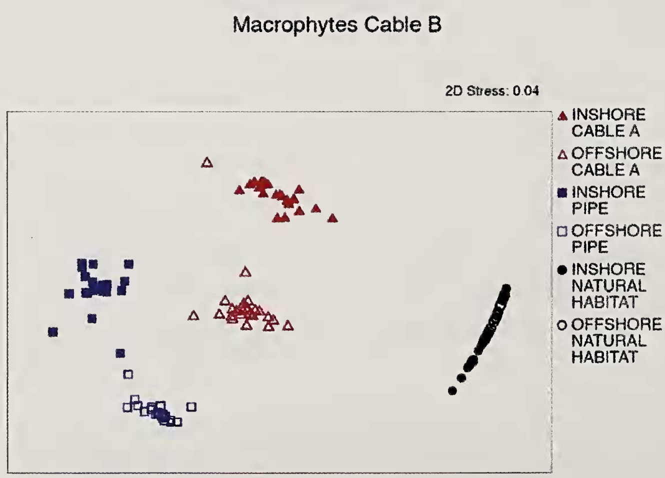

Fig. 10. A 2-d multiple dimensional scaling model comparing the macrophyte assemblages from shallower and deeper transects in Cable B, pipe, and natural habitat.

Table 9. P-values from the repeated measures PERMANOVA testing the effects of habitat (HA), depth (IN), and sampling date (DA) on macrophyte community structure and density of individual taxa and from PERMANOVA pairwise tests for differences between habitats for the periods when Cables B and A were surveyed. Statistically significant effects and differences are underlined.

Cable B	HA	IN	DA	HAxIN	HAxDA	INxDA	Cable, pipe	Cable, natural	Pipe, natural
Macrophyte community	0.0001	0.0001	0.0001	0.0001	0.0003	0.0002	0.0001	0.0001	0.0001
Taxon:									
Zostera marina	0.0001	0.2553	0.0659	0.3820	0.1259	0.3389	0.0001	0.0001	0.0001
Pterygophora californica	0.0001	0.0001	0.0676	0.0001	0.1672	0.5020	0.0001	0.0001	0.0001
Cystoseira spp.	0.0001	0.0026	0.0019	0.0001	0.0001	0.1156	0.0001	0.0001	0.0001
Laminaria spp.	0.0001	0.0001	0.1713	0.0001	0.0574	0.0395	0.0037	0.0001	0.0001
Cable A	HA	IN	DA	HAxIN	HAxDA	INxDA	Cable, pipe	Cable, natural	Pipe, natural
Macrophyte community	0.0001	0.0001	0.0477	0.0001	0.0054	0.2401	0.0001	0.0001	0.0001
Taxon:									
Zostera marina	0.0001	0.0001	0.0215	0.0001	0.0720	0.4107	0.0001	0.0001	0.0001
Pterygophora californica	0.0001	0.0001	0.6193	0.0001	0.5937	0.1637	0.0001	0.0001	0.0001
Cystoseira spp.	0.0001	0.2970	0.0762	0.0001	0.6016	0.2163	0.0001	0.0001	0.0001
Laminaria spp.	0.0001	0.0001	0.8647	0.0001	0.9155	0.2615	0.2039	0.0001	0.0001
Macrocystis pyrifera	0.0001	0.0001	0.0654	0.0001	0.5037	0.0599	0.0001	0.0001	0.0001

Table 10. Total count across all habitats and mean (SE) number of macrophytes per transect in each habitat during period when cable B and cable A were surveyed, 1 February 2012—15 May 2013 and 14 June 2013–26 February 2014, respectively. Two transects, shallow and deep, were surveyed in each habitat on each date. Number of transect surveys in each habitat when Cable B and Cable A were surveyed, n=46 and n=28, respectively.

Cable B	Total Count	Cable Mean	Cable SE	Pipe Mean	Pipe SE	Natural Mean	Natural SE
Zostera marina	19453	16.96	3.41	0.00	0.00	405.93	28.21
Pterygophora californica	16490	344.98	36.11	13.50	2.55	0.00	0.00
Cystoseira spp.	5223	15.65	2.50	97.89	6.02	0.00	0.00
Macrocystis pyrifera	329	3.54	1.37	3.61	1.37	0.00	0.00
Laminaria spp.	2123	18.26	3.05	27.89	4.34	0.00	0.00
Cable A	Total Count	Cable Mean	Cable SE	Pipe Mean	Pipe SE	Natural Mean	Natural SE
Zostera marina	22791	14.36	2.97	0.07	0.07	799.54	50.88
Pterygophora californica	886	20.29	1.11	11.36	2.33	0.00	0.00
Cystoseira spp.	2943	17.11	1.97	88.00	8.43	0.00	0.00
Macrocystis pyrifera	5228	163.07	33.66	23.64	5.14	0.00	0.00
Laminaria spp.	892	12.39	2.61	19.46	3.80	0.00	0.00

Algae also grew on the cable, particularly *Macrocystis pyrifera* on the shallower area of Cable A, and *Laminaria* sp. on the deeper portion of both cables. However, *M. pyrifera* does not form luxuriant bottom structures and the *Laminaria* stands, while present, did not present as dense a cover as the *Cystoceira* on the pipe. The sandy natural habitat was the least complex of all three; its two-dimensional aspect was only broken up by stands of *Z. marina*. At the start of the study *Z. marina* was only sporadically found and became more abundant over time.

Structural variability aside, the results of our study demonstrated that the fish and invertebrate assemblages of the three habitats were similar. Although a few species statistically varied in abundance between the cables and pipe, in no instance was a fish or invertebrate species extremely abundant at one of these two habitats and extremely rare or absent from the other. And although fishes were statistically larger at the pipe than at the cable or natural habitat, we argue that this difference (of less than one-half centimeter between pipe and cable and two centimeters between pipe and natural habitat) is not biologically meaningful.

Results of this study found no evidence that any species of fish or invertebrate was either preferentially attracted to, or repelled by, the EMF emitted by the cables. Any observed differences in the fish or invertebrate densities between cables, pipe, and natural habitat taxa are most likely due to the differences in the physical characteristics of these habitats. For example, the higher densities of YOY *Sebastes* and *E. jacksoni* at the pipe are most likely due to greater densities of understory algae, specifically *Cystoseira* spp. In addition, the lower-relief cables, which were closer to the sandy sea floor, were a better habitat for soft-bottom dwelling sanddabs. Contrary to the fish and invertebrate assemblages, the plant communities on cables, pipe, and natural habitat were clearly different from one another. However, if cable EMF were responsible for these differences, we would expect to see similarities in plant communities between energized cables A and B and this was not the case. Rather, it appears that plant communities were driven by site depth (particularly among the algae) and habitat type (i.e., eelgrass).

We note that this study was not designed to directly determine the behavior of fishes and invertebrates when these organisms encounter an energized cable during, for instance, migrations. Rather, we observed the integration over time of myriads of such behaviors by many organisms. Understanding how individuals within a taxon relate to energized cables would have to involve

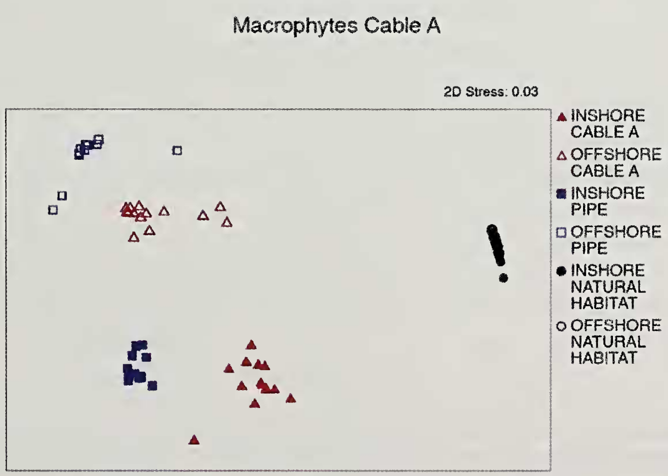

Fig. 11. A 2-d multiple dimensional scaling model comparing the macrophyte assemblages from shallower and deeper transects in Cable A, pipe, and natural habitat.

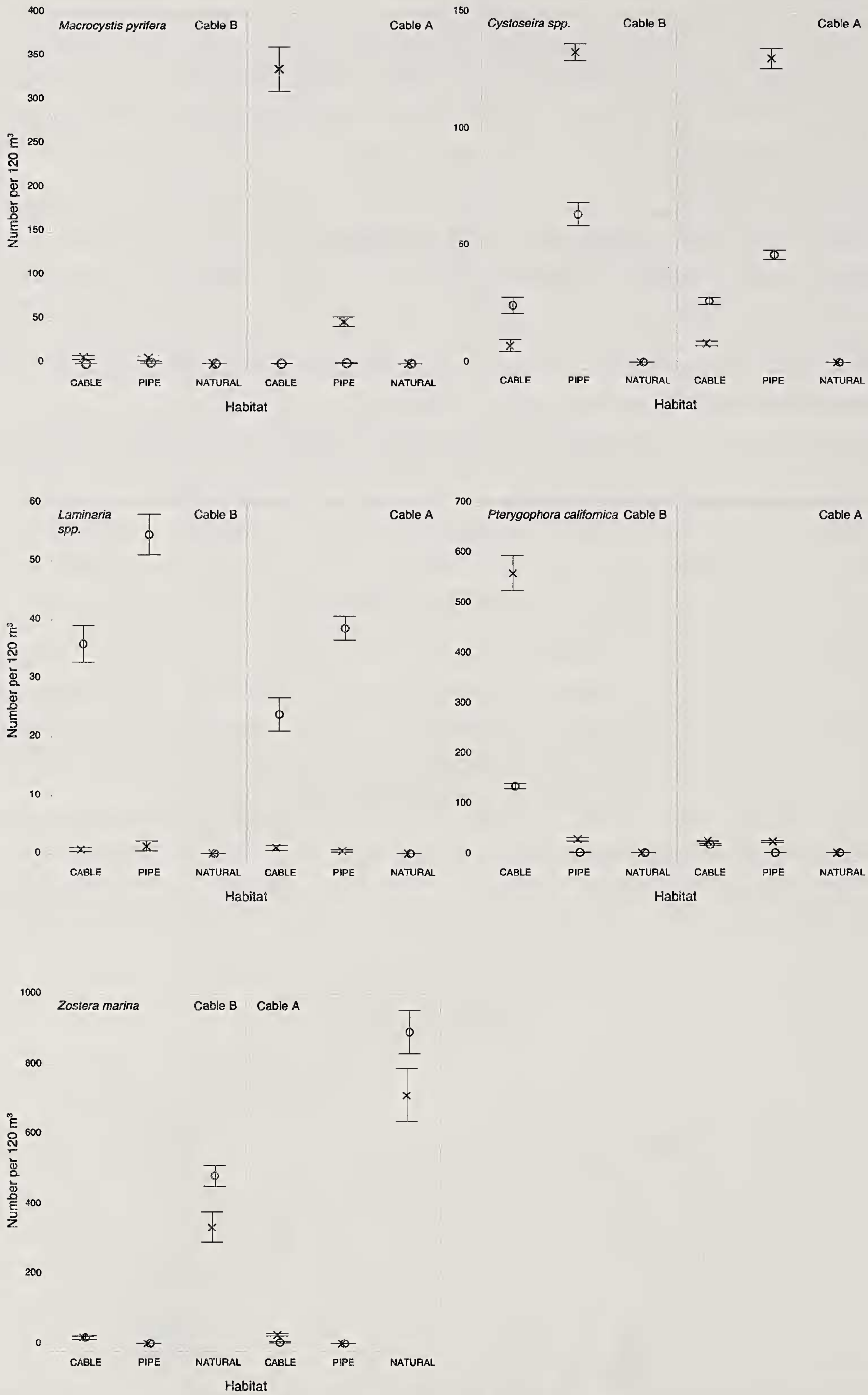

Fig. 12. Mean macrophyte species densities found at the shallower and deeper sites at the three habitats. Data is divided into two periods when 1) Cable B was surveyed and 2) when Cable A was surveyed.

either tracking (Westerberg and Lagenfelt 2008) or caging experiments (Love et al. 2015) or hybrids of the two (Gill et al. 2009).

In southern California, most along-shore migrations (as distinct from less synchronized movements) are conducted by such pelagic species as *Prionace glauca* and *Sardinops sagax*. The more substrate-associated shallower species (exemplified by the taxa that dominated our survey) tend to be either resident (i.e., *Cephaloscyllium ventriosum*, *E. jacksoni*), make seasonal shallower-deeper movements (*H. caryi*), or locally disperse as they mature (YOY *Sebastes* spp., *C. aggregata*). Given that the EMF emitted from the study cables is undetectable beginning at a distance of about one meter (Love et al. 2015, Love unpubl. data) it would be unlikely that pelagic and midwater species are affected by this field. In fact, the limited range of the EMF implies that only the movements of those species that live close to the bottom would be potentially impacted.

In our study area, some of the bottom-dwelling or bottom-oriented species most likely to respond to energized cables are the elasmobranchs: the sharks, skates, and rays. It is probable that all of these fishes can detect an EMF and this ability appears to be used for a number of behaviors including migration and food detection (Kalmijn 1971, Tricas 1982, Klimley et al. 2005). Moreover, while the actual sensitivity to an EMF is known for only a few elasmobranch species, we note that at least two Atlantic species, *Carcharhinus plumbeus* and *Sphyrna lewini*, are able to detect an EMF in the 25–100μT range (Meyer et al. 2005); this is within the range generated by the current surveys' energized cables.

The shallower habitats of southern California, and specifically this study site, harbor a rich diversity of elasmobranchs (Love 2011). These include both mobile taxa (e.g., *Triakis semifasciata* and *Mustelus* spp.) and more sedentary species (*Rhinobatos productus*, *Platyrhinoidis triseriata*, and *Squatina californica*). Given this diversity, it is interesting to note that over the course of this study we observed only two elasmobranch individuals, *C. ventriosum* near the pipe and *Urobatis halleri* near Cable B. It might be argued that the chances of seeing individuals of the more motile species would be small on any given day; although these chances would likely be increased if the animals were attracted to the cables. However, if the more sedentary species were similarly attracted, one might expect to have encountered them. And again, the absence of these animals from the cable is likely not because the EMF generated is below their sensory threshold. Rather, the data strongly imply that of the electro-sensitive species in the study area, at least the elasmobranchs are not attracted to the energized cables.

Our findings are particularly important because, worldwide, the small number of field or semi-field studies that have been conducted on how fishes respond to energized power cables have found either little or no response (Westerberg and Lagenfelt 2008, DONG Energy and Vattenfall A/S 2006, Love et al. 2015, present study) or, arguably, an equivocal one (Gill et al. 2009). One possible explanation is that marine organisms respond to human-made EMF differently from those produced in nature. Recent studies demonstrate that human-made EMF is inherently different from naturally produced EMF, with naturally produced EMF being polarized and consequently more biologically active (Panagopoulos et al. 2015). Thus, it is possible that electro-sensitive organisms are able to differentiate between the two types and therefore respond differently to each of these stimuli.

Regarding the specific objectives of this study:

1) *Differences exist among fish and invertebrate communities associated with energized and unenergized cable habitat and those communities in soft seafloor habitats lacking cables.*

We did not find any biologically significant differences among fish and invertebrate communities between energized cables, pipe, and natural habitat. In particular, only three species of fish showed statistically significant, but slight, differences in densities between the cables and pipe. Plant communities did differ among habitats and within habitats between depths. These differences were almost certainly structure and depth, rather than EMF, related.

2) *Electro-sensitive species that are regionally important, such as sharks and rays, respond (via either attraction or repulsion) to the EMFs of an* in situ *power transmission cable.*

We observed two elasmobranch individuals, *C. ventriosum* near the pipe and *Urobatis halleri* near one of the two energized cables, during the course of this study. Thus, it would appear that the EMFs generated by energized cables are either unimportant to these organisms or that at least other environmental factors take precedence.

3) *The potential effectiveness of the commonly proposed mitigation of cable burial.*

Given the rapidity with which the EMF produced by the energized cables diminishes and the lack of response to that EMF by the shallower fish and invertebrates, cable burial would not appear necessary strictly for biological reasons. In this and similar cases, cable burial, at sufficient depth, would be an adequate tool to prevent EMF emissions from being present at the seafloor.

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